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Thesis

THE DEVELOPMENT OF THE THREE ELECTRODE VACUUM TUBE

Submitted by

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(A.B., St. Genevieve's, 1916)

In partial fulfilment of requirements for

the degree of Master of Arts.

1926

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OUTLINE.

The Development of the Three Electrode Vacuum Tube.

1. The Evolution of the Vacuum Tube Detector..
    1. The Glow Lamp.

        Thomas Alva Edison..
    2. Molecular Shadows in the Glow Lamp.
    3. Edison's Discovery - The Edison Effect.
    4. William H. Preece's Investigations with the Glow Lamp.
    5. John Ambrose Fleming's Work on the Phenomena of Molecular Shadows..

        His Conclusions.
    6. Guthrie's Contribution..
    7. Elster and Geitel's Experiments..
    8. Joseph J. Thomson's Discovery of the Nature of the Electricity Emitted from Hot Bodies.
    9. Owen W. Richardson's Explanation of the Mechanism of Thermionic Emission.

2. Fleming's Oscillation Valve..
    1. Construction.
    2. Operation.
    3. First Practical Application of the Edison Effect.

3. DeForest's Three Electrode Vacuum Tube.

    1. Introduction of the Third Electrode.
    2. Operation of the Tube.
    3. Uses in Radio Telegraphy and Radio Telephony.
        (a) Simple Detector.
        (b) Combined Rectifier and Amplifier.
        (c) The Armstrong Circuit.
        (d) Oscillation Generator.
        (e) Transmitter for Radio Telephony.

4. Various Types of Vacuum Tubes.

    1. Kenetron.
    2. Tungar Rectifier.
    3. Pliotron.
    4. Dynatron.
    5. Magnetron.
    6. Donle Tube.
    7. 110-Volt Tube.

The Development of the Three Electrode Vacuum Tube.

After several years of experiment, Thomas Alva Edison, an American Inventor, gave to the world, in 1880, the first incandescent electric light.

In its earliest form, this glow lamp consisted of a small, partially evacuated, glass bulb, in which was inserted, for filament, a slender, hairpin-shaped platinum wire which was heated to incandescence by an electric current.

This filament, however, was so expensive that the price of the bulbs was almost prohibitory. Accordingly, Edison experimented with various other metals, with cardboard, silk, cotton, flax, and almost every conceivable substance in order to find a cheaper substitute.

Finally, carbon was found to have great resisting power to the electric current; and fine, carbonized bamboo strips proved satisfactory in the tests. So bamboo filaments, in the form of a horse shoe, were inserted in the bulbs, which were exhausted to a higher vacuum than for the platinum wires, in order to prevent combustion.

In spite of great precaution in its manufacture, the life of the glow lamp was uncertain. The inside of the bulb would gradually become coated with a deposit which, being opaque, would soon lessen the intensity of the diffused light, and so impair its usefulness. Moreover, the carbon filament seemed to disintegrate with time.

Edison was curious as to the cause of this bulb blackening, and performed many experiments to see if he could not find some remedy to prolong the life of his lamps. In the course of these researches, he observed a peculiar fact; the above mentioned blackening of the interior of the tube was not regular, but darker in some places than in others. Frequently, a line of no blackening could be seen on one side of the bulb in the plane of the carbon loop, forming what Edison called "Molecular Shadows". Edison concluded that, under certain conditions, and in some unexplainable way, the carbon molecules were shot off in straight lines from some point in the filament; and that the opposite side of the filament acted as a sort of shield, thus preventing the darkening of the glass directly in front of it.

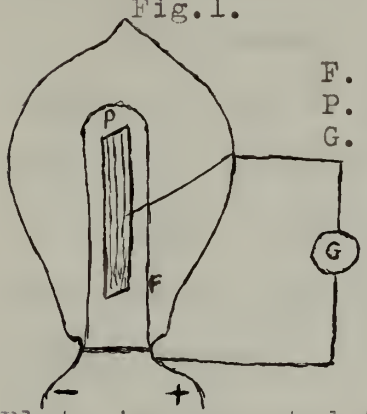
Investigating further, Edison found this special point of bombarding to be at a place on the negative leg where a spot of maximum resistance, due perhaps to some defect in the wire, had caused a greater rise of temperature than at other places along the rest of the filament.

While studying the curious behavior of his bulbs, a novel idea occurred to Edison, and accordingly, in 1883, he made and patented what was really our first vacuum tube.

It resembled, in construction, his original glow lamp but contained an additional electrode, in the form of a metal plate or wire, inserted between the two legs of the filament and attached to an insulated wire sealed through the walls of the bulb.

The Edison Effect.

Fig.1.



F. Filament.
P. Plate.
G. Galvanometer.

Plate is connected to the positive leg of the filament. Result: A current in the plate circuit.

Fig.2.

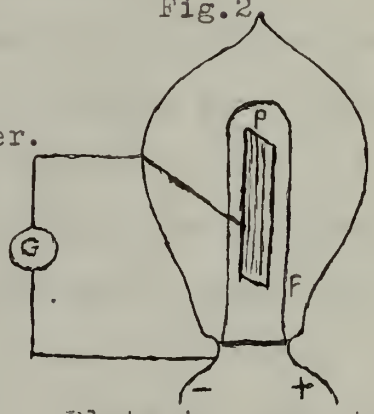


Plate is connected to the negative leg of the filament. Result: No current in the plate circuit.

Edison noticed that when the lead wire from the plate was connected to a galvanometer and the filament heated to incandescence by a direct current, there was a pronounced deflection of the needle provided the galvanometer was attached to the positive terminal of the carbon wire. (Fig. 1.). Little or no sensible current could be detected if the connections were reversed; (Fig. 2.)., which indicated that an electric current was apparently traveling from the filament, through the evacuated space, to the plate; and Edison could not make the current flow otherwise but in this one direction.

This interesting phenomenon soon became known as the"Edison Effect in Glow Lamps", a name given to it by William Preece. Edison, however, could give no explanation of its cause because electrons, at that time, were not known; and the whole phenomena hinges on the theory of the electronic emission from heated metals.

"You cannot use your eyes to help you in the investigation", he said, "and you really know nothing of what is going on in that tiny bulb".

Edison made no practical commercial application of this form of tube, and, in due course of time, his patent expired.

The next important step in the evolution of our present day vacuum tube was brought about by research work of William H. Preece, an English physicist. For his investigations, Preece employed tubes secured from Edison, some similar to those used by the latter in experimenting with the "Edison Effect", and others with tubular extensions in which the cold plate was sealed.

Early in 1885, Preece read a paper before the Royal Society of London, - "On the Peculiar Behaviour of Glow Lamps When Raised to High Incandescence" - which gave the results of his research on this subject. The more important points presented by him at this time were:-

(1). When the filament is heated to incandescence, a current flows between filament and plate.

(2). The amount of this current is independent of the material of the metal plate.

(3). The metal plate need not be placed between the legs of the filament, nor in its immediate vicinity. It can even be inserted in a sort of side arm of the main tube; and a current will be observed, provided that the tube and its annex are not bent at right angles to each other.

Preece naturally surmised that the Edison Effect must be due to some straight line propagation of the carbon molecules from the heated filament.

In his address, Preece simply stated the facts as he himself had found them, and, like Edison, refrained from attempting to explain scientifically the peculiar phenomena he had observed.

In 1882, John Ambrose Fleming, of England, had been appointed advisor to the Edison Electric Light Company of London. While serving in that capacity, he had become much interested in the research of Edison and Preece on the Molecular Shadows and the Edison Effect. His position provided a fine opportunity of becoming thoroughly acquainted with their work as well as of examining for himself the unusual behavior of the Glow Lamp.

Wishing to investigate at greater length, Fleming accordingly secured, in 1888, a number of lamps with carbon filaments and central metal plates and began his experiments which were, a few years later, to give such a stimulus to the advance of Radio all over the world.

In 1889, 1890, and 1896, Fleming appeared before the Royal Society, The Royal Institution, and The Physical Society, of London, and explained the results of his investigations.

Fleming confirmed all of Preece's previous discoveries, but he went somewhat further. He showed:-

(1). That if the metal plate of the evacuated tube were connected to an electroscope and the filament heated, the leaves would diverge, indicating a charge; which charge proved by tests to be always negative.

(2). If the electroscope were previously charged positively, heating the filament would cause the leaves to collapse. Therefore, he concluded that it was negatively charged atoms or molecules which the filament in some unexplainable way gave off when incandescent.

(3). This negative current always flowed from the negative side of the filament to the plate.

(4). If the negative side of the filament were surrounded by metal or glass, or even shielded by a mica screen placed between it and the plate, the Edison Effect was thereby diminished or annihilated. But if the other

leg of the wire were treated likewise, the Edison Effect was not impaired.

(5). If the filament were incandescent and a conductor connected to the plate, such conductor was immediately discharged provided it were initially positive, but was not affected if first given a negative charge.

Fleming repeated his experiments, substituting in one case a platinum wire for the carbon filament and in another a wire grid, of similar area, for the metal plate. He found substantially the same results.

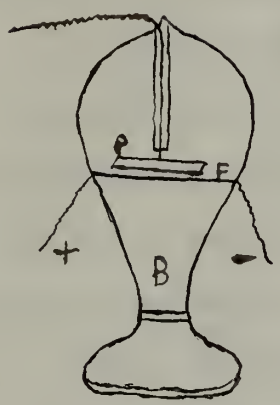
This transmission of electricity from hot bodies was not exactly a new idea. Early in 1873, F.Guthrie had published a paper, "On a Relation Between Heat and Static Electricity", in which he mentioned an important discovery concerning heated bodies. Viz:-

(1). A ball at red heat can retain a negative charge but not a positive one.

(2). A ball at white heat can retain neither a positive nor a negative charge.

In 1880-1889, Elster and Geitel of Germany, made a thorough investigation of Guthrie's discovery, but unlike the latter, they frequently used for their experiments a heated filament, enclosed in a partially

exhausted glass bulb. Above this filament they suspended a platinum plate, supported by a wire sealed in the top of the tube.



"B" Glass bulb with adjustable vacuum.

"F" Incandescent wire.

"P" Metal plate.

Bulb used by
Elster and Geitel.

With this apparatus Elster and Geitel studied, systematically, the phenomena of the loss of electricity from hot bodies in vacuo, the impartation of electric charges to nearby insulated conductors, and the effects of the contact of gases with heated wires. They found:-

(1). In a partially evacuated bulb, the filament seemed to give off positive electricity at low temperatures, and negative at high ones.

(2). The tendency to emit positive electricity diminished and finally disappeared with increase of evacuation of the bulb.

The results of their research work, which was purely scientific, were published in Wiedermann's Annalen in 1882, and 1889.

By 1895, it was generally known that heated wires, or incandescent filaments in vacuo, emitted negative electricity; but no one had been able to find out the nature of this emission.

In 1896, Rontgen had discovered the X Rays of the Cathode Tube, and scientists had tried to explain the phenomenon on the hypothesis of a stream of minute, electrically charged ions or corpuscles being given forth by the metal on which the cathode rays impinged.

Using this hypothesis as the basis of his experiments, Joseph J. Thomson, of England, in 1897-1899, investigated the discharge in vacuum tubes and the conduction of electricity through gases, in an endeavor to discover the exact nature of this negative electricity.

By ingeniously arranged experiments, Thomson not only proved the existence of negatively charged bodies, weighing some two thousand times less than hydrogen atoms, and so confirmed the corpuscular hypothesis, but he even calculated the relation of the mass of these particles to their charge.

In 1900, Thomson announced his startling discovery viz; that the electricity emitted from hot bodies comes not from atoms of matter, but in reality from infinitesimally minute particles of negative electricity (electrons): and that the electric current,

which had been observed in previous phenomena in the vacuum tubes, was due to the drifting of these electrons.

In 1901, Owen W. Richardson, of England, from purely theoretical reasoning and using Thomson's disclosures as a basis, developed his theory for the mechanism of thermionic emission, and made important quantitative determinations. He declared that electrons (he called them thermions) would evaporate from any metal provided it were sufficiently heated; and, since the current from an incandescent filament depends upon the number of electrons given off, such current should increase with rise of filament temperatures. From his conclusions, Richardson deduced the formula: $1 = aT^{\frac{1}{2}} E^{-\frac{b}{t}}$ :: where 1 is the electron emission per square cm. of the hot body whose absolute temperature is T , a and b are constants,; e is the base of the Naperian logarithms.

Then in 1902-1903, Richardson carried out actual experiments to confirm his theory, and substantiated all his statements. But others were also investigating the same subject, and their results did not always agree with Richardson's, so it was not until some years later that the electron theory of thermionic emission was really established.

A most important step in the development of radio communication was the discovery, by J. A. Fleming, in 1904, that the unilateral conductivity of electricity, observed in the Edison Effect with direct currents, could also be utilized to rectify high frequency alternating currents.

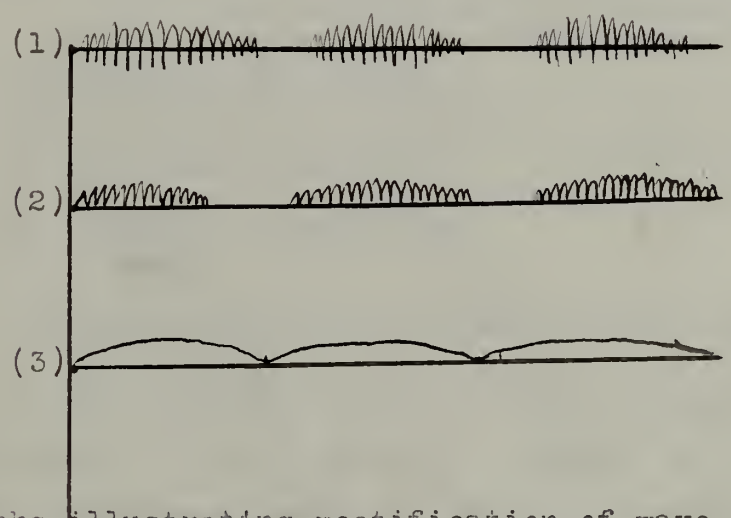
In his experiments, Fleming employed a two electrode vacuum tube which did not differ essentially from those used by him in his previous investigations; and since he found that the tube would permit the current to pass in but one direction, he called it an Oscillation Valve.

In its simplest form, this valve consists of a glass bulb, highly evacuated, in which are sealed two electrodes, adjacent, but not touching; for cathode, a filament which can be heated by a battery, and for anode, a metal plate, either oblong in form or cylindrical or spiral encircling the filament.

When the filament is heated, electrons are given off into the evacuated space of the bulb. These are attracted to the plate, which, having no charge, is at a higher potential than the filament. A current is thereby set up which lasts as long as the difference of potential is maintained.

When the tube is used as a detector, the plate

is connected to the source of incoming alternating currents. These electric impulses are of radio frequency and in a form too rapid to affect the human ear or the telephone receiver. They give the plate alternately a positive and then a negative potential. But the electron current will flow only when the plate is positively charged. Thus one half of the Alternating Current Cycle is destroyed. The result in the receiver is a modulated direct current at audio frequency, with one pulse for each wave train.



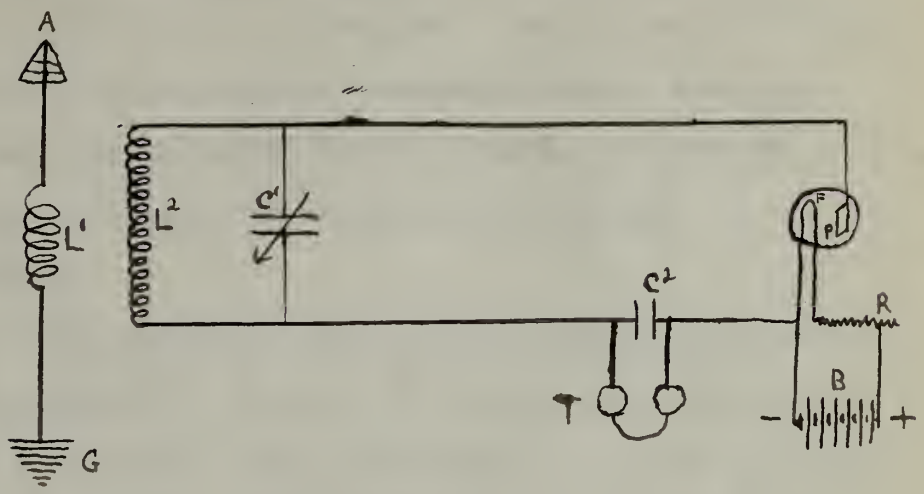
Graphs illustrating rectification of wave trains by a Valve.

(1). Radio Frequency Group.-Incoming oscillations.

(2). Rectified Current.-Negative Half Cycles Missing.

(3). Audio Frequency Pulses.-Telephone Currents.

The Two Electrode Tube as a Detector.



A. Antenna.
B. Battery which heats the filaments and supplies current to the plate circuit.
C-1 Variable condenser for tuning.
C-2 Small condenser which stores up the rectified currents and discharges them periodically through the earphones.
L-1 Primary Inductance.
L-2 Secondary Inductance.
R. Rheostat for varying the filament current.
T. Telephone receiver.
F. Filament of vacuum tube.
P. Plate of vacuum tube.
G. Ground.

Fleming found later that the sensitiveness of the tube was much greater if the plate was charged positively by connecting it to the positive terminal of a second battery, whose negative terminal was attached to the hot filament.

Fleming, when he applied the one way conductivity to the reception of signals in wireless telegraphy, was the first to make any practical application of the Edison Effect. His Oscillation Valve may be called our first Vacuum Tube Detector.

In 1906, Lee DeForest, an American, made a remarkable contribution- the great step in the evolution of the vacuum tube. He took Fleming's Valve, and, by simply inserting in it an extra element, produced a little bulb which has revolutionized wireless communication.

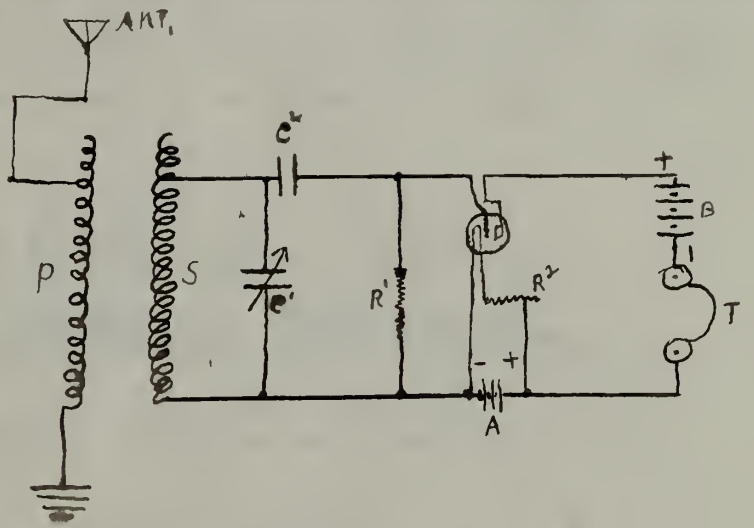
In 1907, DeForest patented his device which he called an Audion. It consists of an ordinary vacuum tube with a separate third electrode, a sort of zig-zag spiral or perforated wire gauze interposed between the upright filament and the plate. This extra piece, which DeForest named the "Grid", is attached indirectly to the antenna and acts as a sort of control gate for the streaming electrons which must pass through its meshes in their journey from the incandescent filament to the positively charged cold plate.

The incoming waves set up oscillations in the antenna and so impress a voltage on the grid which exerts a marked influence on the number of electrons reaching the plate. The oscillations give the plate alternately a positive and then a negative potential, causing a fluctuation in the plate current, reducing it when negative on account of repelling the incoming electrons and increasing it when positively charged by drawing more electrons from the filament. The grid is exceedingly sensitive and responds to alternations of

very high frequency and to the feeblest of signals.

DeForest's tube is used in both radio telegraphy and telephony as a detector, an amplifier, and a generator of high frequency currents. One arrangement of the three electrode vacuum tube as a simple detector is as follows:-

The Three Electrode Vacuum Tube as a Detector.



P. Antenna inductance.
S. Secondary inductance.
C-1 Variable condenser for tuning.
C-2 Grid condenser.
R-1 Grid leak to limit charge accumulating on the grid.
R-2 Filament rheostat to control the filament temperature.
A. Battery for incandescing the filament.
B. Battery for applying voltage to the tube.
T. Telephone receivers.

When the antenna and secondary circuits are properly tuned, the variations in the amplitude of the incoming high frequency currents cause fluctuations in the grid potential and so produce surges, at radio frequency, in the plate current. The average plate current rises and falls once for each oscillation group;

and it is this which causes the diaphragm of the telephone receivers to vibrate at audio frequency. Since the negative half of the alternating current is suppressed, waht is really a rectified current is produced.

Graphs showing how the three electrode vacuum tube converts damped oscillations into pulsating direct currents producing audible responses in the receiving telephones.

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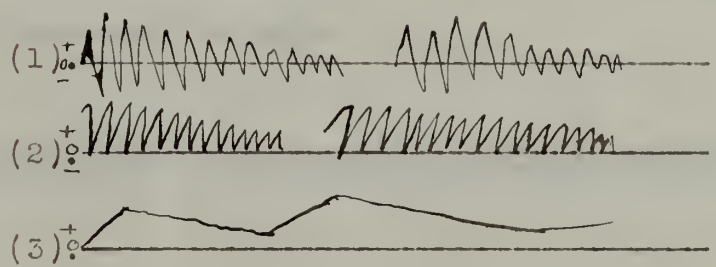


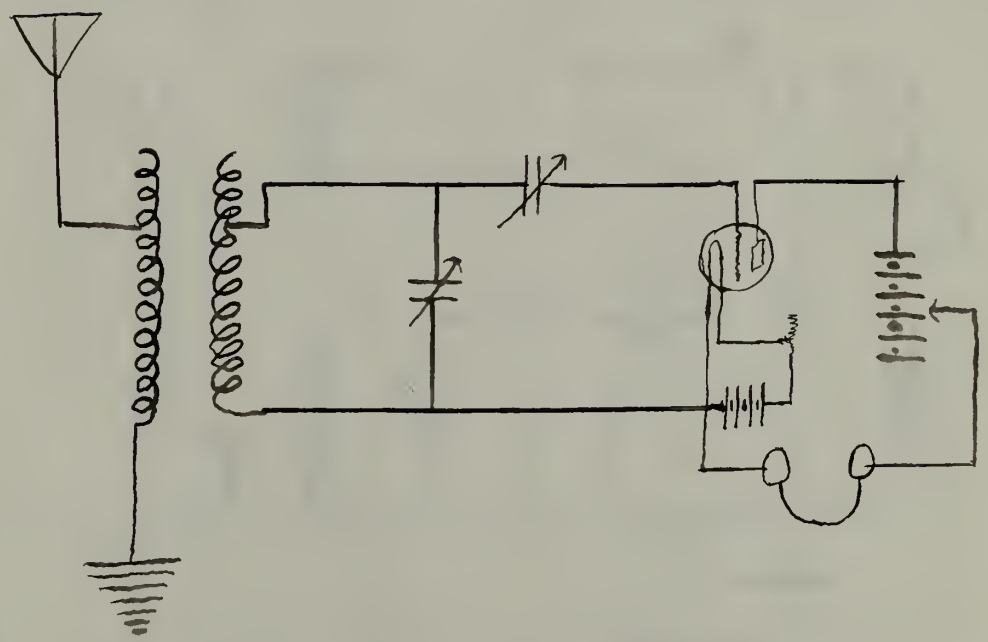
(1). Oscillations in the grid circuit.

(2). Radio frequency variations in the plate circuit.

(3). Current in the phone circuit.

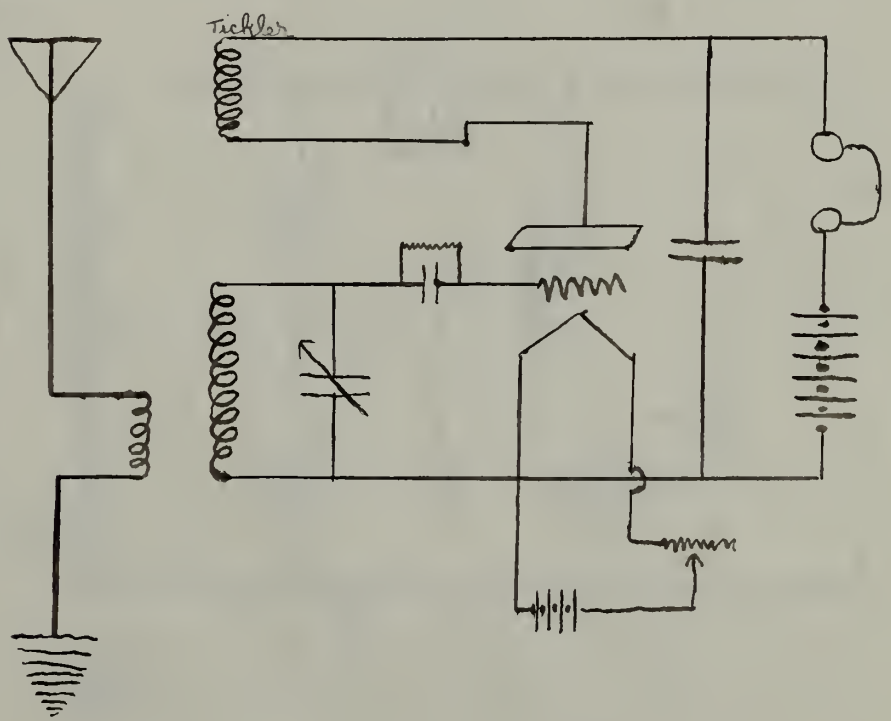
In its action, the three electrode vacuum tube, like Fleming's valve, does not follow Ohm's Law. Because a very slight variation of potential at the grid produces a greatly magnified fluctuation in the plate current and therefore in the telephones connected to it, the vacuum tube acts as an amplifier of the electric oscillations received. The extra power is supplied by the "B" battery, and the resultant amplification equals the amplification factor of the tube (ratio of change in plate voltage to change in grid voltage) multiplied by the impressed voltage.

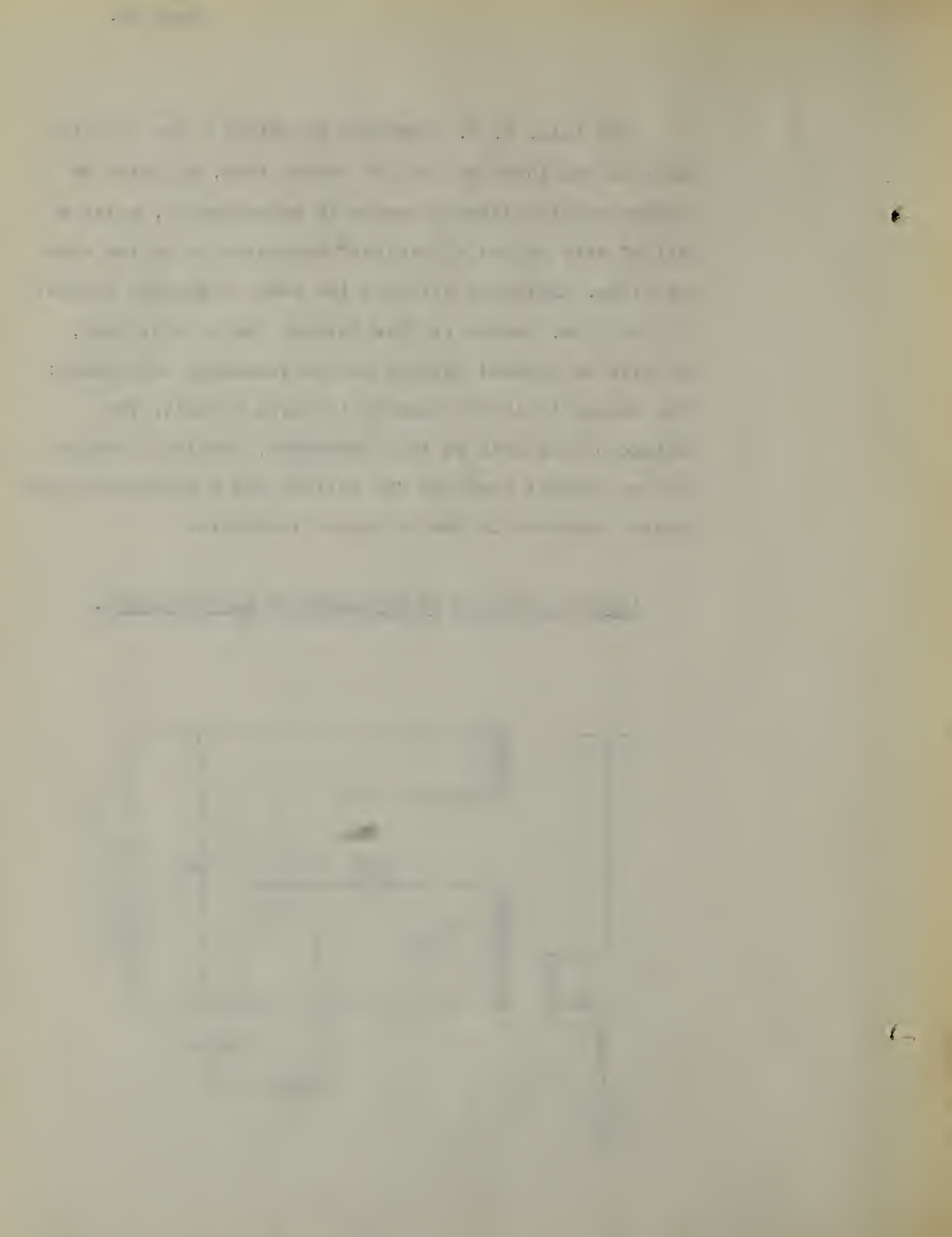
The Vacuum Tube as a Combined Rectifier and Amplifier.



In 1914, E. H. Armstrong described a new circuit which he had invented for the vacuum tube, in which he secures amplification by means of regeneration, using a coil of wire called a "tickler" connected in series with the plate. Armstrong utilizes the radio frequency current of the plate, having it flow through the tickler coil, and give an induced voltage to the secondary inductance; from whence it is fed back to the grid circuit. The voltage of the grid is thus increased, causing a larger flow of current from the "B" battery and a correspondingly greater response in the telephone receivers.

Armstrong Method of Regenerative Amplification.

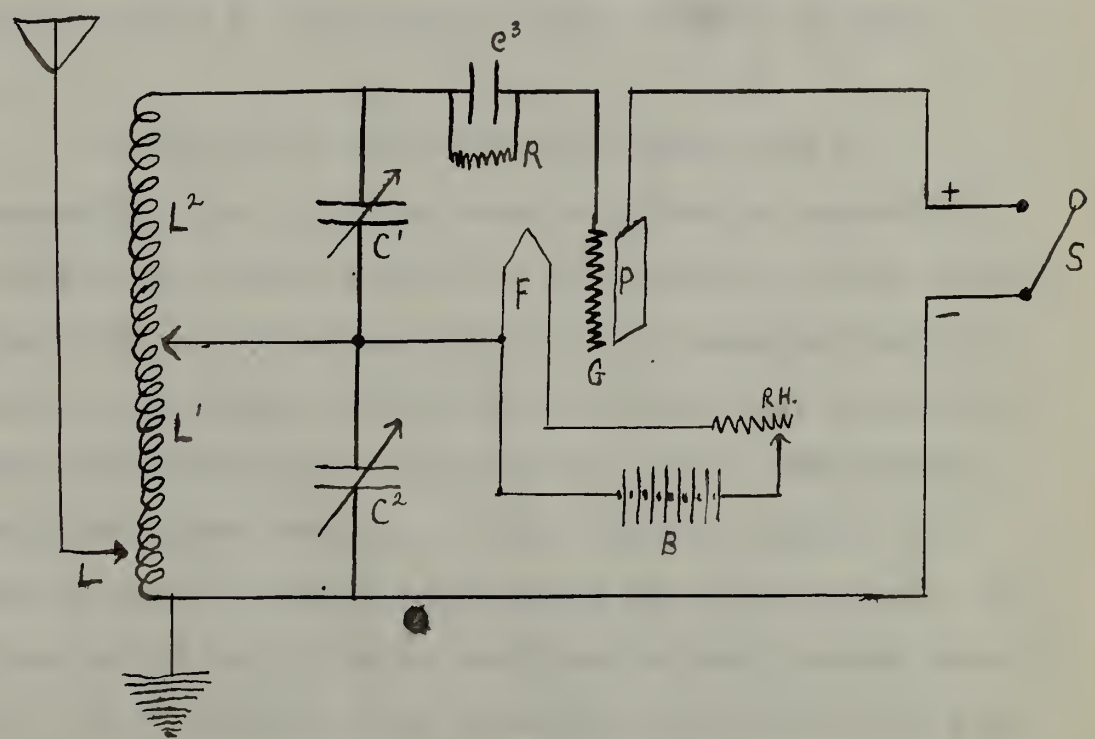




In 1912, while DeForest was experimenting with his amplifiers, he was several times annoyed by the howling and squealing of some of the tubes. On investigating the cause of this disturbance, he found that when the grid and plate circuits were linked in a certain way, the tube became a generator of electric oscillations. Thus DeForest accidentally discovered that his tubes could be used, not only as excellent detectors and amplifiers of radio signals, but also as generators of high frequency alternating currents.

In generating oscillations, "hard" tubes i.e. those with high vacuum are used, so that they will not break down so easily.

Oscillation Generator. Wireless Telegraphy.



Reference for Diagram Shown on Page Nineteen.

P. Plate of vacuum tube.
G. Grid.
F. Filament.
B. Battery for heating filament.
R.H. Rheostat to maintain filament at correct temperature.
R. Grid leak resistance.
S. Switch - source of direct current.
C-1 Variable condenser.
C-2 Variable condenser.
C-3 Grid condenser.
L. Antenna.
L-1 Plate inductance.
L-2 Grid inductance.

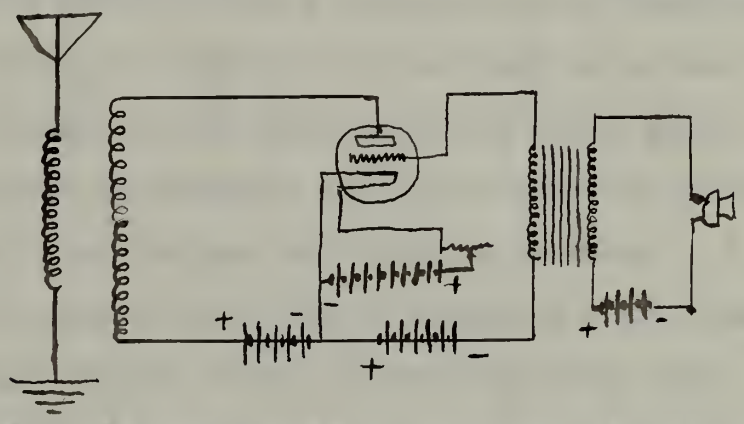
Each time the key is closed, oscillations are produced which, being impressed on the antenna cause radio frequency waves to be sent out into the ether. The frequency of these waves is controlled by varying the inductance and the capacitance. Dots and dashes are produced according to the length of time the key is held down.

The action of the three electrode tube in generating these high frequency alternating currents is as follows;- When the switch S is closed, a direct current flows from S, stores up energy in the condenser C-2 and sets up a magnetic field around the coil L-1. A current also flows from the filament to the plate. The magnetic field collapses when C_2 is fully charged, giving the grid a negative charge which stops the plate current. The discharge of C-2 produces oscillations and induces them in coil L-2. The alternating potential supplied to the grid

causes variations in the plate current and sets the plate circuit oscillating. This induces a greater potential variation in the grid circuit which in turn increases the amplitude of the oscillations in the plate circuit, one circuit continuing to react on the other until the whole system is vibrating steadily.

In radio telephony, the vacuum tube is connected so as to produce undamped oscillations. This gives the carrier wave. The microphone with its battery is connected indirectly to the grid.

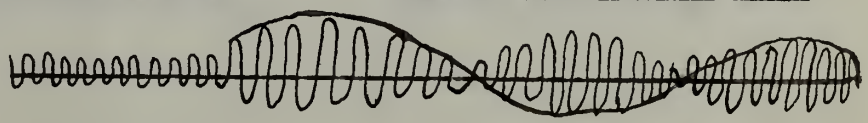
Oscillation Generator. Radio Telephony.

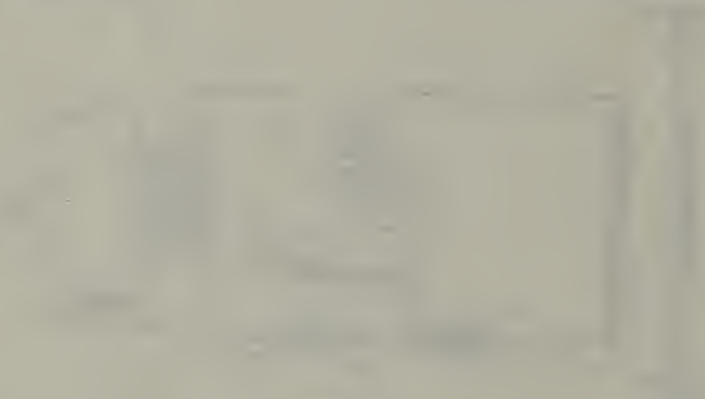


When the sound waves go through the microphone, they cause fluctuations in the oscillations sent out by the antenna. Thus the carrier wave is modulated at audio frequency and is given the same wave form as the sound waves themselves..

Molding of the Carrier Wave into Speech Form.

Steady continuous wave. Speech controlled wave.





Radio Engineers were soon interested in DeForest's three electrode vacuum tubes and have made many structural improvements in it, producing tubes with little resemblance to the originals of 1906. Today, vacuum tubes are on the market under various trade names, e.g. Kenetrons, Pliotrons, Tungar Rectifiers, Dynatrons, Donle non-interfering detector, 110 volt tube, Magnatrons, Radiotrons etc.

The Kenetron is a modern form of the two electrode vacuum tube. It was developed in the research laboratories of the General Electric Co., largely through the work of Irving Langmuir, Saul Dushman, and William White. In contrast to the audion, it has its bulb exhausted to the highest degree which gives a tube of consistent performance and one very serviceable in rectifying high voltage alternating currents.

The Tungar Rectifier is simply a modification of Fleming's valve. Both filament and plate are generally made of tungsten, and the bulb is filled with argon gas. In contrast to the Kenetron, its chief use is in charging storage batteries by rectifying low voltage alternating currents.

The Pliotron, also a product of the General Electric Co., is a Kenetron fitted with a tungsten grid of very fine wires which, by means of its electrostatic field, controls the current between the filament and plate.

The Dynatron is a special form of high vacuum tube containing a very heavy grid. It was developed largely through the efforts of Albert Hull, and utilizes, in its action, the secondary emission of electrons from the charged plate.

The Magnatron makes use of an external magnetic field in place of the grid. The filament gives off electrons, which, in passing to the anode, are deflected at right angles to the magnetic field created around the filament, the amount of deflection depending on the strength of the filament heating current.

In 1923, in the laboratory of the General Electric Co. a very large magnetron was built by A. W. Hull measuring three feet in length. It has a concentric cylindrical anode, 30 x 1 3/4 inches; and a tungsten filament 0.4 x 22 inches, which, if drawn out, would make fifty miles of ordinary filament wire. The anode is water cooled and the tube can deliver 1000 kilowatts of power.

In the Donle tube, the anode, of metallic sodium, is placed in a sort of well in the bottom of the bulb. A piece of high resistance wire is cemented to the outside of the glass directly underneath the anode in order to heat the metal. Above the anode, and suspended by the filament, is a new element termed the "collector". It is a semi-cylindrical piece of sheet metal with the open side facing downwards. The tube is very sensitive and reliable, and does not interfere with reception in

neighboring receivers.

The 110 volt vacuum tube consists of a filament suspended from the top of the tube and enclosed in a porcelain cylinder. The entire apparatus is surrounded by a casing of a metal which has the property of freely emitting electrons at low temperature. The action of the tube is unusual. When the filament is incandescent, heat is radiated from it to the porcelain, and then transferred to the metal sheath which acts as the cathode of the tube and emits electrons.

It is difficult to tell just where the development of the vacuum tube will end. New uses are continually being found for the powerful little bulbs, not only in wireless communication, but also in many of the Arts.

To satisfy such widespread application, tubes have been built from one inch to several feet in height; and already several types of four electrode vacuum tubes are being exploited.

SUMMARY.

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In 1880, Thomas Alva Edison produced the first incandescent electric light globes.

In 1883, while experimenting with his lamps, and seeking some method to increase their usefulness, Edison made a discovery later known as the"Edison Effect" in glow lamps.

He introduced a metal plate into one of his bulbs and observed that a small current flowed between the incandescent filament and the added electrode, provided the plate was positive with respect to the filament, but not if it were negatively charged.

Edison's lamp was our first vacuum tube.

In 1885, William Preece did much research work with Edison's bulbs but could not explain the phenomena he observed.

In 1889-1896, John A. Fleming further investigated the Edison Effect but made no practical application of it at that time.

In 1899, Joseph J. Thomson measured the mass and charge of the electron and attributed the Edison Effect phenomena to electrons.

In 1901, Owen W. Richardson explained the theory of thermionic emission from heated filaments and substantiated his statements by actual experiments.

In 1904, J. A. Fleming applied Edison's device to the rectification of alternating currents and to the reception of wireless signals. Fleming called his tube an "Oscillation Valve".

This was our first Vacuum Tube Detector.

In 1906, Lee DeForest immensely improved the sensitivity of the two electrode vacuum tube by inserting a third electrode, the grid, between the filament and the plate. The grid serves as a control for the electrons which are attracted to the cold plate from the incandescent filament.

DeForest called his three electrode tube an "Audion". DeForest's tubes, or modifications of them, have found widespread uses.

BIBLIOGRAPHY.

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The Thermionic Valve and its Development in Radiotelegraphy and Telephony.
John Ambrose Fleming.
Wireless Press Ltd. London 1919.

Thermionic Tubes in Radio Telegraphy and Telephony.
John Scott-Taggart.
Wireless Press Ltd. London 1921.

Vacuum Tubes in Wireless Communication.
Elmer Eustice Bucher.
Wireless Press Inc. New York 1918.

The Wireless Experimenter's Manual.
Elmer Eustice Bucher.
Wireless Press Inc. New York 1922.

Wireless Telegraphy.
Bernard Leggett.
Chapman & Hall Ltd. London 1921.
(pp.110-202 and 399-425)

Principles of Radio Communication.
John H. Morecroft.
John Wiley & Sons Inc. New York 1921.
(pp. 1-200 and 364-577)

Fifty Years of Electricity.
John Ambrose Fleming.
Wireless Press Ltd. London 1921.

Radio Telephony.
Alfred N. Goldsmith.
Wireless Press Inc. New York 1918.

Radio Telephony for Amateurs.
Stuart Ballantine.
David McKay Co. Philadelphia 1923.
(Second Edition).

Radio: Beam and Broadcast. Its Story and Patents.
Arthur Hyatt Morse.
Ernest Benn Ltd. London 1923.

The Oscillation Valve.
R. D. Bangay.
Wireless Press Ltd. London 1919.

Wireless of Today.
Charles R. Gibson and William R. Cole.
Seeley Service Co. Ltd.,London 1924.

Maxwell's Theory and Wireless Telegraphy.
Jules Henri Poincaré and Frederick King Vreeland.
Part 2 by F.K.Vreeland.
McGraw Pub. Co. New York 1904.

Electricity and Magnetism.
Sydney G. Starling.
Longmans Green Co. 1912.
(pp. 406-560).

Conduction of Electricity through Gases.
Joseph John Thomson.
University Press, Cambridge 1903.
(Chapters 5 and 8).

The Emission of Electricity from Hot Bodies.
Owen Willans Richardson.
Longmans Green Co. London, (Part Only).

The Corpuscular Theory of Matter.
Joseph J. Thomson.
Chas. Scribners & Sons 1907.
(Part Only).

Principles of Electric Wave Telegraphy.
John Ambrose Fleming.
Longmans Green CO. New York 1906.
(Part Only).

Magazine Articles.

Bell System Technical Journal.

Thermionic Vacuum Tubes and Their Applications.
Robert W. King.
October 1923.

General Electric Review.

The Pure Electron Discharge and Its Applications in Radio, Telegraphy and Telephony.
Irving Langmuir.
May 1915.

The Vacuum---There's Something in It.
W.R.Whitney.
July 1924.

General Electric Review. (Cont).

A New Device for Rectifying High Tension Alternating Currents- The Kenetron.
Saul Dushman.
March 1915.

High Voltage Rectifiers.
A.Schmidt, Jr.
February 1923.

Radio Communication.
W. R. G. Baker.
September 1922.

30 Kilowatt 15,000 Volt Rectifier for the U. S. Navy.
A.Schmidt, Jr.
May 1923.

Journal of the American Institute of Electrical Engineers.

The Edison Effect and Its Modern Applications.
Clayton H. Sharp.
January 1922.

Sensitive Radio Frequency Relay.
George Lewis.
November 1924.

The Axially Controlled Magnetron.
Albert W. Hull.
October 1923.

Note on the Development of an Electron Tube Amplifier Which Uses 60- Cycle Alternating Current to Supply Power for the Filament and Plates.
P. D. Lowell.
July 1922.

Proceedings of the Institute of Radio Engineers.

Thermionic Tubes.
Frederick S. McCullough.
December 1922.

A New Non-Interfering Detector.
Harold P. Donle.
April 1923.

Proceedings of the Institute of Radio Engineers.

The Dynatron - A Vacuum Tube Possessing Negative Resistance.
Albert W. Hull.
February 1918.

Radio Telegraphy.
Senatore Guglielme Marconi.
August 1922.

Recent Developments in High Vacua Receiving Tubes-
Radiotrons - Models UV-199 and UV-201.
J. C. Warner.
December 1923.

Digests of U. S. Patents Relating to Radio Telegraphy and Telephony During 1924.
John B. Brady.
1924.

The Electric Review.

The New Thermionic Tube.
John Scott-Taggart.
February 27, 1920.

The Electrician.

Thermionic Vacuum Tube as Detector, Amplifier, and Generator of Electric Oscillations.
W. H. Eccles.
May 1920.

A New Method of Magnifying Electric Currents.
E. Reiss.
February 6, 1914.

The Audion - A New Receiver for Wireless Telegraphy.
Lee DeForest.
November 23, 1906.

The Audion - Detector and Amplifier.
Correspondence . . Fleming and DeForest.
Nov. 21, Dec. 5, 1913, and Jan. 23, 1914.

A Detector Coefficient. . Its Use in Testing the Capabilities of Three Electrode Valves.
John J. Dowling and Joseph M. Higgins.
November 13, 1925.

The Electrician. (Cont).

The Valve and Oscillation Generator.
Dallas G. Bower.
October 9, 1925.

A 200 k.w. Triode Transmitter.
Baltimore - Van Der Poland and K. Posthumus.
August 21, 1925.

The Physical Review.

The Unilateral Dynamic Characteristics of Three Electrode Vacuum Tubes.
John C. Frayne.
June 1922.

Electrical World.

Vacuum Tube Amplifiers.
Lieut. Max G. Batsel.
March 22, 1919.

War Time Development of Vacuum Tubes.
Capt. Ralph Bown.
February 22, 1919.

The Electrical Journal.

The Radio Vacuum Tube.
H. M. Freeman.
November 1922.

Engineering.

A Phenomenon of the Edison Lamp.
December 12, 1884.

Science.

Vacuum Tube Amplifier in Scientific Work.
October 20, 1922.

Nature.

Researches in Radio Telegraphy.
December 9, 1909.

Scientific Monthly.

The Water Cooled Vacuum Tube and Trans-Atlantic Telephony.
December 1925.

Outlook.

Radio's Magic Wand.
May 31, 1922.

American.

The Greatest Marvel of the Twentieth Century In Electricity.
Keene Sumner.
February 1922.

The Man Who Made Radio Broadcasting Possible.
Owen McLean.
February 1924.

Radio Broadcast.

Tubes--Their Uses and Abuses.
Keith Henney.
December 1925.

Uses of the Three Electrode Tube.
June 1924.

Radio News.

History of Radio Inventions.
A. H. Morse.
July - August 1925.

Life and Work of Lee DeForest.
W. B. Arfin.
September 1925.

Hard Tubes and Soft Tubes as Amplifiers and Detectors.
C. B. Bazzoni.
October 1925.

Scientific American Supplement.

Thermionic Detectors.
November 3, 1917.

Wave Detectors for Wireless.
J. A. Fleming.
December 8, 1917.

Radio Telephony - - Parts 1 - 2 - 3.
E. B. Craft and E. H. Colpitts.
April 19, 26, May 3, 1919.

The Origin of the Thermionic Vacuum Tube.
Philip E. Edelman.
January 3, 1918.

Experimental Wireless Telegraphy and Telephony Part V11.
Louis Gerard Pacent and Austin C. Lescarcoura.
November 8, 1919.

The Audion.
Lee DeForest.
November 30, December 7, 1907.

Recent Contribution to Electric Wave Telegraphy.
J. A. Fleming.
September 21,1907.

Wave Detectors for Wireless..The Oscillation Valve.
J. A. Fleming.
December 8, 1917.

Literary Digest.

The Amazing Power Tube.
November 25, 1922.

Scientific American.

Will the Direct Current Era Return?
Raymond Francis Yates.
April 1922.

The Vacuum Tube--An Electric Acrobat.
Pierre H. Bucheron.
January 17,1920.

Our Alladdin's Lamp. - Recent Developments in Vacuum Tubes.
January 1923.

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